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(71) Applicant (*for all designated States except US*): MCDONNELL DOUGLAS CORPORATION [US/US]; P.O. Box 516, St. Louis, MO 63166-0516 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): FERRANTE, Ronald, Alfred [US/US]; 2531 MacBeth Avenue, Corona, CA 91720 (US). OTT, Rudolph, Herman [US/US]; R.R. 1, Box 92, Batchtown, IL 62006 (US).

(74) Agents: GOSNELL, Guy, R. et al.; Bell Seltzer Intellectual Property Law Group, Alston & Bird LLP, P.O. Drawer 34009, Charlotte, NC 28234 (US).

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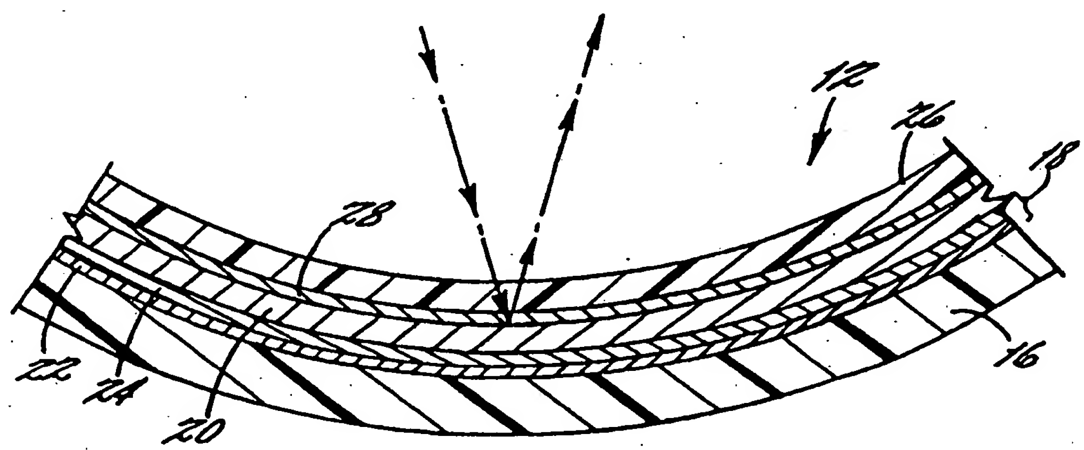
(54) Title: REFLECTOR AND ASSOCIATED LIGHT ASSEMBLY



(57) Abstract

The reflector (10) includes a substrate (16) and a plurality of intermediate layers which include at least one bonding layer (18) disposed upon the substrate and a metallic reflectance layer (20) disposed upon the bonding layer. The bonding layer includes a first dielectric layer (22), such as aluminum oxide (Al_2O_3), for bonding or adhering the metallic reflectance layer to the substrate. The reflectance layer is preferably comprised of a silver material which reflects a high percentage of the incident light. In addition, the reflector can include a protective layer (26), such as a layer of Leybold Mark 3 material, for protecting the underlying bonding and reflectance layers, such as from tarnishing and other environmental degradation. As a result, the reflector provides a relatively high level of reflectance which does not degrade over time since the reflectance layer remains tightly adhered to the substrate and since the reflector is protected from tarnishing. In addition, the reflector can be curved in order to further focus the reflected light.

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REFLECTOR AND ASSOCIATED LIGHT ASSEMBLY

BACKGROUND OF THE INVENTION

The present invention relates generally to reflectors and associated light assemblies and, more particularly, to curved reflectors having a relatively high reflectance.

Lighting reflectors are employed in a variety of applications to enhance the resulting brightness provided by a light source. For example, aircraft and spacecraft include a number of reflectors both externally and internally, such as within a cockpit display or a helmet mounted display. In addition, flash jet paint removal systems, such as described by U.S. Patent No. 5,328,517, can include one or more reflectors for increasing the intensity of the light focused upon the painted surface of an aircraft. Most commonly, automobiles and other vehicles typically include a number of reflectors in order to increase the brightness of the head lamps or other exterior or interior lighting systems.

Conventional lighting reflectors are typically formed of aluminum or include an aluminum coated surface to enhance the resulting brightness. While an aluminum or aluminum coated surface reflects approximately 80 to 90 percent of the light energy, the reflector absorbs the remainder of the light energy as heat, thereby creating significant inefficiencies. As a result, more sophisticated reflectors have been

developed to reflect a greater percentage of the incident light.

For example, reflectors which include a plurality of dielectric coating layers have been developed. In order to provide sufficient reflectance, however, the thickness of each dielectric layer must be precisely controlled, thereby increasing the complexity of the fabrication process. In addition, reflectors must oftentimes be curved in order to properly direct the reflected light. Accordingly, it is even more difficult, if not impossible, to precisely control the thickness of each dielectric layer of a curved dielectric coated reflector.

Reflectors which do not include dielectric layers, but which include silver based coatings have also been developed in order to provide improved reflection efficiency. While reflectors which include silver based coatings typically require less precision with respect to the thickness of the various layers, reflectors which include silver based coatings commonly have poor adhesion. As a result, the silver based coatings may release, in whole or in part, from the underlying substrate, thereby significantly impairing the reflectance of the reflector. In addition, reflectors which include silver based coatings typically tarnish following exposure to air over time, thereby further diminishing the performance of the reflector.

Therefore, while it would be desirable for a lighting reflector to reflect a greater percentage of the incident light than conventional aluminum or aluminum coated reflectors, the reflectors currently available all suffer from several deficiencies. For example, dielectric coated reflectors require the dielectric layers to have a specific thickness, thereby complicating the fabrication process particularly with respect to the fabrication of curved reflectors.

Moreover, reflectors which do not include dielectric layers, but which include silver based coatings typically tarnish and suffer from poor adhesion, thereby impairing the performance of these reflectors.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide an improved reflector which reflects a high percentage of the incident light.

It is another object of the invention to provide a reflector which is relatively insensitive to variations in the thickness of the individual coating layers.

It is a further object of the invention to provide a reflector which includes coating layers that are tightly adhered to the underlying substrate.

It is yet another object of the invention to provide a curved reflector which can be easily fabricated.

It is still another object of the invention to provide a reflector which includes a silver reflectance layer which does not readily tarnish.

These and other objects are provided, according to the present invention, by a reflector which includes a substrate and a plurality of intermediate layers including at least one bonding layer disposed upon the substrate and a metallic reflectance layer disposed upon the bonding layer. The bonding layer includes a first dielectric layer, such as aluminum oxide (Al_2O_3), for bonding or adhering the metallic reflectance layer to the substrate. The reflectance layer is preferably comprised of a silver material which reflects a high percentage of the incident light. In addition, the reflector of the present invention can include a protective layer, such as a layer of Leybold Mark 3 material, for protecting the underlying bonding and reflectance layers, such as

from tarnishing and other environmental degradation. As a result, the reflector of the present invention provides a relatively high level of reflectance which does not degrade over time since the reflectance layer remains tightly adhered to the substrate and since the reflector is protected from tarnishing.

In order to further improve the adherence of the reflectance layer to the substrate, the bonding layers can include a copper (Cu) layer disposed between the first dielectric layer and the reflectance layer. In addition, the reflector of one advantageous embodiment includes a second dielectric layer between the reflectance layer and the protective layer in order to adhere the protective layer thereto.

Since the metallic reflectance layer reflects the incident light, the reflector of the present invention is relatively insensitive to variations in the respective thicknesses of the bonding and reflectance layers. However, the reflectance layer is preferably thicker than each of said bonding layers. In particular, the reflector of one advantageous embodiment includes bonding and reflectance layers which have respective predetermined thicknesses, i.e., optical thicknesses, based upon the predetermined wavelength λ of light which the reflectance coating preferentially reflects. For example, the predetermined thickness of the reflectance coating preferably equals $\frac{k\lambda}{4}$ for a positive odd integer k, while the predetermined thickness of each bonding layer preferably equals $\frac{(2m+1)\lambda}{32}$ for a positive whole number m. As a result, the reflector of this embodiment can be tailored to preferentially reflect light of a predetermined wavelength λ by controlling the respective thicknesses of the bonding and reflectance layers.

Although the reflector of one advantageous embodiment includes bonding and reflectance layers which have respective predetermined thicknesses, the reflector of the present invention remains relatively insensitive to variations in the thicknesses of the bonding and reflectance layers. Thus, the reflector can be curved since the bonding and reflectance layers can be readily deposited upon a curved substrate. As a result, the curved reflector of this embodiment of the present invention can form a portion of a lighting assembly which also includes a light source disposed adjacent the concave surface of the curved reflector.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of a lighting assembly including a curved reflector according to one advantageous embodiment of the present invention.

Figure 2 is a cross-sectional view of the curved reflector illustrated in Figure 1 which depicts the various bonding, reflectance and protective layers.

Figure 3 is a graph illustrating the reflectance of a reflector according to one embodiment of the present invention as a function of wavelength in comparison to the reflectance of a conventional aluminum coated reflector as a function of wavelength.

DETAILED DESCRIPTION OF THE INVENTION

Various methods and apparatus embodiments of the invention are set forth below. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiment set forth herein. To the contrary, the invention includes numerous alternatives, modifications, and equivalents as will become apparent from consideration of the present specification including the drawings, the foregoing discussion, and the following detailed description. Like numbers refer to like elements

throughout. In addition, the thicknesses of the various layers have been exaggerated in the drawings for purposes of clarity.

Referring now to Figure 1, a light assembly **10** according to the present invention is illustrated. The light assembly can be employed in a variety of applications, such as automotive, aircraft, spacecraft and other applications as will be apparent to those skilled in the art. The light assembly includes a reflector **12** and a light source **14**, such as a light bulb. As shown in Figure 1, the reflector can be curved so as to define a concave surface and a convex surface. However, the reflector can have other shapes or can be planar without departing from the spirit and scope of the present invention.

As shown in more detail in Figure 2, the reflector **12** of the present invention includes a substrate **16** and a plurality of intermediate layers disposed upon the substrate. The substrate **16** can be formed of various materials, such as glass, aluminum or a plastic material. While the intermediate layers can be deposited upon the substrate in a variety of manners without departing from the spirit and scope of the present invention, the intermediate layers are typically deposited upon the substrate with a chemical vapor deposition (CVD) process.

The intermediate layers include at least one bonding layer **18** disposed upon the substrate **16** and a reflectance layer **20** disposed upon the bonding layer. The bonding layers include a first dielectric layer **22** which adheres the reflectance layer to the substrate. As a result, the reflectance layer will remain tightly adhered to the substrate such that the reflector **12** of the present invention will continue to provide high reflectance over time. According to one advantageous embodiment, the first dielectric layer is formed of aluminum oxide (Al_2O_3). In other embodiments, however,

the bonding layers need not include a dielectric layer, but can include a bonding layer formed of other materials, such as gold.

As shown in Figure 2, the bonding layers **18** of one advantageous embodiment also include a copper (Cu) layer **24** disposed between the first dielectric layer **22** and the reflectance layer **20**. The copper layer further adheres the reflectance layer to the first dielectric layer and, in turn, to the substrate **16**. While the bonding layers of this advantageous embodiment include a copper layer, the bonding layers can, instead, include a layer formed of gold without departing from the spirit and scope of the present invention. In addition, while the reflector **12** of Figure 2 includes two bonding layers, namely, the first dielectric layer and the copper layer, the reflector can include additional bonding layers, such as additional dielectric layers, without departing from the spirit and scope of the present invention.

The reflector **12** of the present invention preferably includes a reflectance layer **20** formed of a silver (Ag) material. For example, the reflectance layer can be formed of silver and/or silver alloys. However, the reflectance layer can be formed of other metallic materials, such as gold, without departing from the spirit and scope of the present invention. The reflectance layer is designed to reflect light incident thereon. In particular, the reflectance layer can be formed as described hereinbelow such that the light of a predetermined wavelength λ or a predetermined range of wavelengths are preferentially reflected.

The reflector **12** also preferably includes a protective layer **26** disposed upon the reflectance layer **20**. The protective layer protects the underlying bonding and reflectance layers from tarnishing and other environmental degradation. The protective layer

is preferably formed of a hard material in order to further protect the underlying bonding and reflectance layers. For example, the protective layer is preferably formed of Leybold Mark 3 (MK3) material which is available from Leybold-Heraeus GmbH of Munich, Germany. However, the protective layer can be formed of other materials, such as MgF_2, without departing from the spirit and scope of the present invention.

The reflector **12** of one embodiment also includes a second dielectric layer **28** disposed between the reflectance layer **20** and the protective layer **26**. The second dielectric layer serves to tightly adhere the protective layer to the reflectance layer and to further protect the reflectance layer. The second dielectric layer is typically formed of the same dielectric material as the first dielectric layer, such as aluminum oxide. However, the second dielectric layer can be formed of other dielectric materials, if so desired. While the illustrated reflector includes a single second dielectric layer, the reflector of this embodiment can include a plurality of dielectric layers between the reflectance layer and the protective layer without departing from the spirit and scope of the present invention.

Since the reflectance layer **20** reflects the incident light, the reflector **12** of the present invention is insensitive to variations in the respective thicknesses of the various layers. Thus, the reflector can be fabricated in a rapid and cost-effective manner with conventional deposition techniques, such as CVD. In addition, the various layers of the reflector can be readily deposited upon a curved substrate **16** in order to form a curved reflector as shown in Figures 1 and 2. Therefore, the reflector of the present invention can be shaped or configured to meet the requirements of the particular application.

Although the reflector **12** of the present invention is insensitive to variations in the respective thicknesses of the various layers, the predetermined wavelength λ of light preferentially reflected by the reflectance layer **20** is determined by the respective thicknesses of the various layers. In particular, the thickness of the reflectance layer equals $\frac{k\lambda}{4}$ for a positive odd integer k. Likewise, the thickness of each bonding layer **18**, such as the first dielectric layer **22** and the copper layer **24**, preferably equals $\frac{(2m+1)\lambda}{32}$ for a positive whole number m. Thus, each bonding layer typically has the same predetermined thickness.

As used herein, the thicknesses of the various layers refers to their respective optical thicknesses. Therefore, the wavelength of light which defines, in part, the mathematical relationship between the thicknesses of the various layers and the wavelength of light preferentially reflected therefrom is the wavelength of light within the respective layers. As known to those skilled in the art, the wavelength of light within a layer formed of a material with an index of refraction n is defined as: $\lambda=\lambda_0/n$ wherein λ_0 is the wavelength of light in air.

The reflectance layer **20** is typically thicker than either of the bonding layers **18**. For example, a reflector **12** designed to reflect blue light having a wavelength of 400 nm will typically include a reflectance layer having a thickness of 1.33 microns, a first dielectric layer **22** having a thickness of 7.6 nanometers and a copper layer **24** having a thickness of 0.15 microns. Thus, the reflectance layer of one advantageous embodiment is about nine times (or more) as thick as either of the bonding layers.

According to one advantageous embodiment, the protective layer **26** and the second dielectric layer **28** also have respective predetermined thicknesses which are the same as the thicknesses of the reflectance layer **20** and a bonding layer **18**, respectively. Thus, the protective layer of this advantageous embodiment is also significantly thicker than any of the bonding layers or the second dielectric layer.

As shown in Figure 3, the reflector **12** of the present invention therefore reflects a greater percentage of the incident light over a wide range of wavelengths than conventional aluminum coated reflectors. Due to the adherence provided by the bonding layers **18**, the reflector of the present invention will continue to reflect a very high percentage of the incident light over time since the reflectance layer **20** will remain tightly adhered to the substrate **16**. In addition, the protective layer **26** will protect the reflector from tarnishing and other environmental degradation, thereby further improving the lifetime and performance of the reflector.

Many modifications and other embodiments of the present invention will come to the mind of one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing description and the associated drawings. Therefore, it is to be understood that the invention is not limited to the specific embodiments disclosed and other embodiments are intended to be included within the scope of the appended claims. Although specific terms have been employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

THAT WHICH IS CLAIMED IS:

1. A reflector comprising;

a substrate;

a plurality of intermediate layers disposed upon said substrate, said intermediate layers comprising:

at least one bonding layer disposed upon said substrate, said at least one bonding layer comprising a first dielectric layer; and

a reflectance layer disposed upon said at least one bonding layer such that said at least one bonding layer adheres said reflectance layer to said substrate, said reflectance layer comprising a silver (Ag) material for reflecting light incident upon the reflector; and

a protective layer disposed upon said plurality of intermediate layers for protecting said underlying bonding and reflectance layers.

2. A reflector as recited in claim 1 wherein said first dielectric layer comprises an aluminum oxide (Al_3O_2) layer disposed adjacent said substrate.

3. A reflector as recited in claim 2 wherein said at least one bonding layer further comprises a copper (Cu) layer disposed between said aluminum oxide (Al_3O_2) layer and said reflectance layer.

4. A reflector as recited in claim 1 wherein said plurality of intermediate layers further comprises a second dielectric layer disposed upon said reflectance layer.

5. A reflector as recited in claim 4 wherein said second dielectric layer comprises an aluminum oxide (Al_2O_3) layer.

6. A reflector as recited in claim 1 wherein said protective layer comprises a layer of Leybold Mark 3 material.

7. A reflector as recited in claim 1 wherein each of said bonding layers and said reflectance layer have respective predetermined thicknesses, and wherein said reflectance layer is thicker than each of said bonding layers.

8. A reflector as recited in claim 7 wherein said reflectance layer is adapted to preferentially reflect light of a predetermined wavelength λ, and wherein the predetermined thickness of said reflectance layer equals $\frac{k\lambda}{4}$ for a positive odd integer k.

9. A reflector as recited in claim 7 wherein the predetermined thickness of each of said bonding layers equals $\frac{(2m + 1)\lambda}{32}$ for a positive whole number m.

10. A reflector comprising:

a substrate;

a first dielectric layer disposed upon said substrate;

a metallic reflectance layer for preferentially reflecting light of a predetermined wavelength, said metallic reflectance layer disposed upon said first dielectric layer such that said first

dielectric layer adheres said metallic reflectance layer to said substrate; and

a second dielectric layer disposed upon said metallic reflectance layer.

11. A reflector as recited in claim 10 further comprising a protective layer disposed upon said second dielectric layer for protecting said underlying dielectric and metallic reflectance layers.

12. A reflector as recited in claim 10 further comprising a copper (Cu) layer disposed between said first dielectric layer and said metallic reflectance layer to further adhere said metallic reflectance layer to said substrate.

13. A reflector as recited in claim 10 wherein said first and second dielectric layers are comprised of aluminum oxide (Al_2O_3), and wherein said metallic reflectance layer is comprised of a silver (Ag) material.

14. A reflector as recited in claim 10 wherein said first and second dielectric layers and said metallic reflectance layer have respective predetermined thicknesses, and wherein said metallic reflectance layer is thicker than each of said first and second dielectric layers.

15. A reflector as recited in claim 14 wherein the predetermined thickness of said metallic reflectance coating equals $\frac{k\lambda}{4}$ for a positive odd integer k, and wherein the predetermined thickness of each of said first and second dielectric layers equals $\frac{(2m + 1)\lambda}{32}$ for a positive whole number m.

16. A light assembly comprising:

a curved substrate;

a reflector disposed upon said curved substrate, said reflector comprising:

at least one bonding layer disposed upon said curved substrate; and

a metallic reflectance layer for reflecting light incident thereon, said metallic reflectance layer disposed upon said at least one bonding layer such that said at least one bonding layer adheres said reflectance layer to said curved substrate; and

a light source disposed adjacent to said curved substrate such that said reflector reflects light emitted by said light source.

17. A light assembly as recited in claim 16 wherein said curved substrate defines a concave inner surface, said reflector disposed upon said concave inner surface of said curved substrate, said light source also disposed adjacent said concave inner surface of said curved substrate.

18. A light assembly as recited in claim 16 wherein said at least one bonding layer comprises a first dielectric layer disposed adjacent said curved substrate and a copper (Cu) layer disposed between said first dielectric layer and said metallic reflectance layer, and wherein said metallic reflectance layer comprises a silver (Ag) material for reflecting the light emitted by said light source.

19. A light assembly as recited in claim 18 wherein said reflector further comprises:

a second dielectric layer disposed upon said metallic reflectance layer; and

a protective layer disposed upon said second dielectric layer for protecting said underlying layers.

20. A light assembly as recited in claim 16 wherein each of said bonding layers and said metallic reflectance layer have respective predetermined thicknesses, and wherein said metallic reflectance layer is thicker than each of said bonding layers.

21. A light assembly as recited in claim 21 wherein said light source emits light of a predetermined wavelength λ, wherein said metallic reflectance coating is adapted to preferentially reflect light of the predetermined wavelength λ, and wherein the predetermined thickness of said metallic reflectance coating equals $\frac{k\lambda}{4}$ for a positive odd integer k.

22. A light assembly as recited in claim 21 wherein the predetermined thickness of each of said bonding layers equals $\frac{(2m+1)\lambda}{32}$ for a positive whole number m.

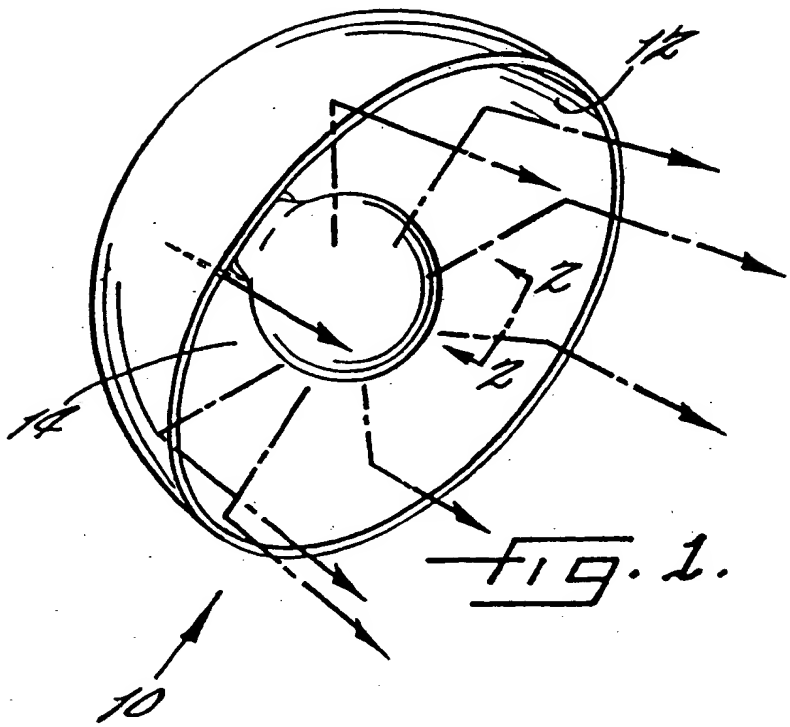

FIG. 1.

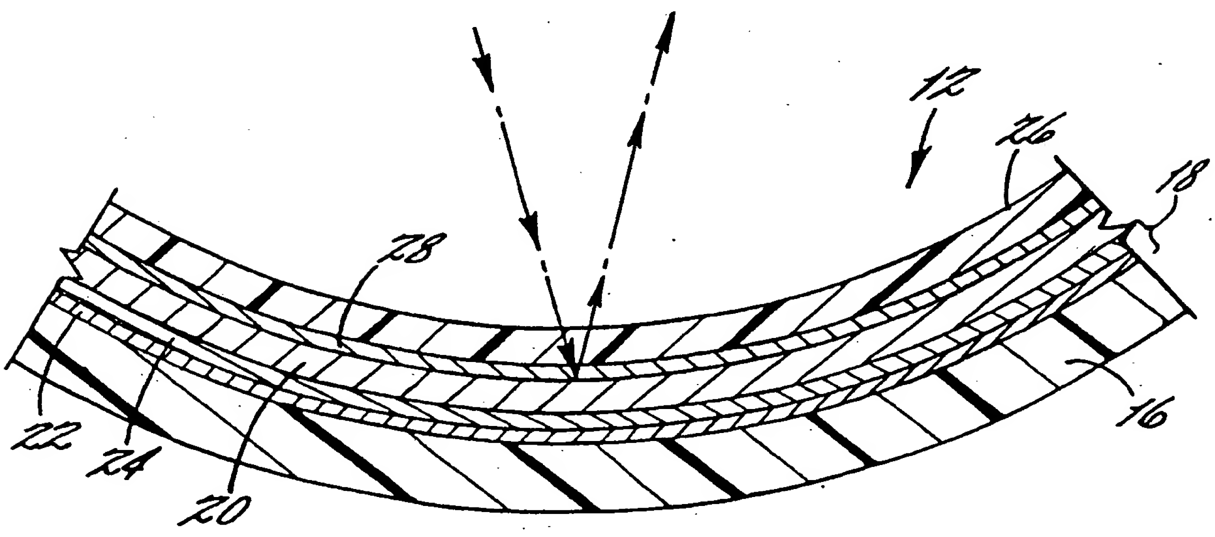

FIG. 2.

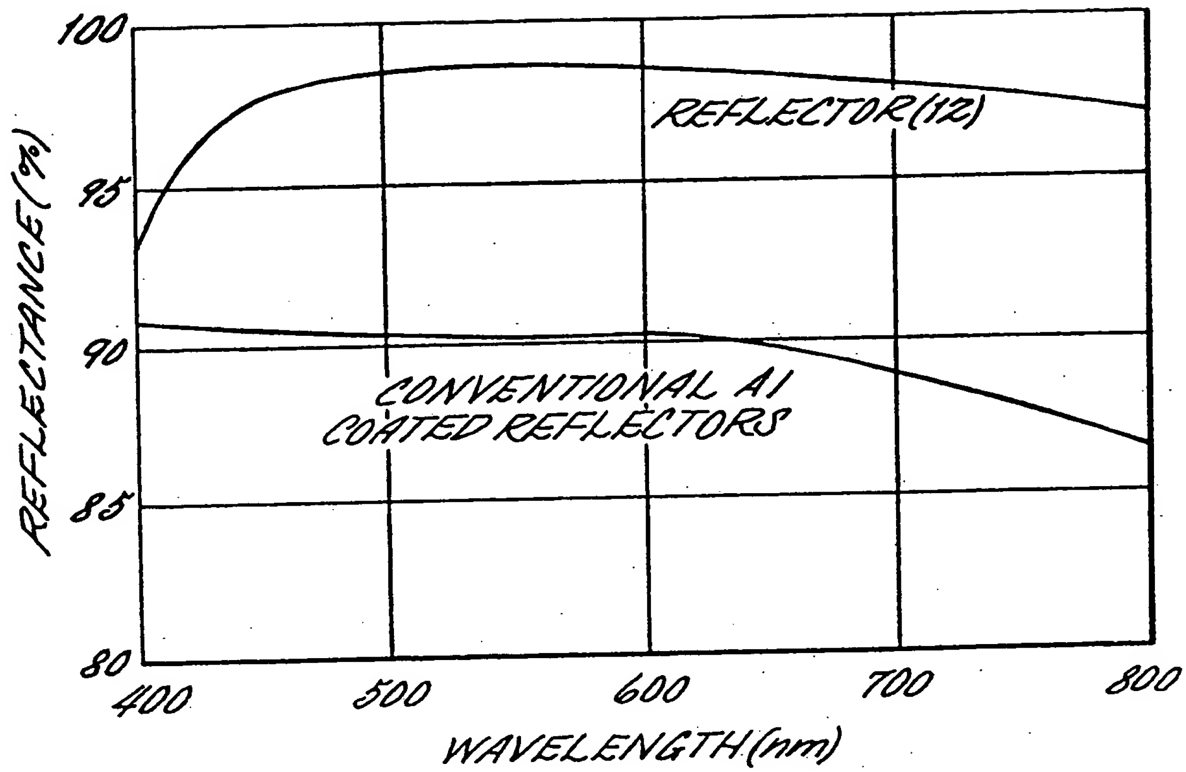
REFLECTANCE (%)
100
95
90
85
80
400
500
600
700
800
WAVELENGTH (nm)
REFLECTOR (12)
CONVENTIONAL Al
COATED REFLECTORS

FIG. 3.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/02392

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F21V7/22

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F21V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 1 953 796 A (CROCKER) 3 April 1934 see page 1, line 79 - line 82 see page 1, line 88 - line 89 see page 2, line 33 - line 47 see page 2, line 103 - line 107 see figures 1-7 ---	1,3,10, 12,16-18

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of theinternational search	Date of mailing of the international search report
15 May 1998	29/05/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Mas, A

INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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